International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(21s) 2026 pp. 808-829
https://doi.org/10.70917/ijcisim-2026-4771
Article

Strategic Implementation of Technology Adoption in Developing Economies: An Integrated DIT-TAM Model of Government Mandate Effectiveness in Malaysia.

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Abstract: Technology adoption in developing economies is often driven by government mandates, yet the extent to which such mandates translate into sustained implementation remains insufficiently understood. This study examines the strategic implementation of Building Information Modeling (BIM) in Malaysia using an integrated framework of Diffusion of Innovations Theory (DIT) and the Technology Acceptance Model (TAM). The study evaluates how government mandates interact with organizational, technological, and perceptual factors to influence BIM adoption and implementation. A survey of 562 Architecture, Engineering, and Construction (AEC) professionals was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). Results indicate strong upstream effects of external variables (organizational culture, people readiness, technology capability, and government policies) on DIT and TAM constructs (β = 0.487–0.546, $p < 0.001$). Among diffusion attributes, trialability had the strongest effect on BIM adoption (β = 0.273), followed by observability (β = 0.239) and compatibility (β = 0.199), accounting for 30.8% of the variance in adoption (R^2 = 0.308). Perceived ease of use (β = 0.512) and perceived usefulness (β = 0.474) significantly predicted BIM usage intention, accounting for 66.1% of its variance (R^2 = 0.661). However, downstream effects on implementation were modest: usage intention (β = 0.255), adoption (β = 0.164), and government policies (β = 0.226) explained only 24.5% of the variance in implementation (R^2 = 0.245). Effect sizes further revealed strong perceptual impacts but weak direct policy influence on implementation (f^2 = 0.053), indicating an implementation gap. The findings reveal a "mandate paradox": policies shape perceptions but do not adequately drive implementation, underscoring the need for supportive enforcement, usability enhancements, and sustained capacity building.
Keywords: Building Information Modeling (BIM), Diffusion of Innovation Theory (DIT), Technology Acceptance Model (TAM), Government Mandates, Technology Adoption, and Developing Economies

1. Introduction

Digital transformation has emerged as a strategic imperative for governments seeking to enhance productivity, transparency, and competitiveness, particularly in developing economies, where public sector reform can unlock broader economic gains. Building Information Modelling (BIM) is widely characterised as a disruptive, data-rich digital process innovation capable of reshaping coordination and analysis across the architecture, engineering, and construction (AEC) lifecycle, and many governments have increasingly promoted or mandated BIM, particularly for public projects, as a means of accelerating sector-wide digitalisation [1,2]. Comparative evidence further indicates that "government-driven" BIM trajectories often evolve through phased roadmaps in which the state shifts roles over time (e.g., initiator, educator, regulator), underscoring that public policy instruments rather than market forces alone can be central to BIM diffusion and institutionalisation [2]. At the same time, BIM has been conceptualised as a systemic innovation whose benefits require multiple interdependent actors (projects, firms, and users) to change practices in a coordinated manner; consequently, diffusion is frequently slow and uneven, sustaining a gap between BIM aspirations and actual practice and motivating policy interventions to promote adoption [1,3]. In Malaysia, BIM is promoted as part of broader construction digitalisation ambitions, yet adoption remains constrained by persistent implementation barriers reported across key stakeholder groups and firm types [4–6]. Empirical work on the quantity surveying profession attributes low BIM uptake to limited awareness and uncertainty about BIM's benefits, indicating that knowledge-related constraints at the individual/professional levels remain salient inhibitors [5]. Complementing this, research on Malaysian SME contractors reports that, despite acknowledged benefits and government promotion efforts, significant difficulties continue to delay BIM adoption, particularly among smaller firms that remain cautious about implementation [4]. Recent stakeholder-focused evidence from Johor likewise finds that many AEC firms remain uninterested in BIM due to anticipated challenges and identifies barriers such as limited stakeholder awareness of benefits and inadequacies in government regulatory standardisation, pointing to simultaneous individual-capability and institutional/regulatory impediments [6]. Collectively, these Malaysia-specific findings substantiate that knowledge/awareness gaps are recurring obstacles to construction digitalisation via BIM, and that adoption constraints extend beyond technology availability to include readiness and policy environment factors [4–6]. However, the Malaysian BIM adoption literature also appears fragmented in analytical scope. Existing studies frequently examine adoption through bounded lenses, for example, profession-specific awareness and perceptions (quantity surveyors) [5], firm-type-specific challenges (SME contractors) [4], or region- and stakeholder-sampled barrier inventories (Johor AEC stakeholders) [6]. This pattern is consistent with the broader observation that systemic innovations such as BIM require multilevel alignment across users, firms, projects, and institutions, suggesting that single-level or narrowly scoped studies can struggle to explain why adoption remains slow even when benefits are well-publicised and policy attention exists [1,3]. Relatedly, BIM localisation research argues that lukewarm adoption can reflect misfit between a generally conceived innovation and the regulatory, social, and cultural settings of a locality, implying the need for frameworks that explicitly integrate contextual and institutional conditions with adoption mechanisms [7]. Thus, while Malaysian evidence richly documents stakeholder- and organisation-specific constraints, there remains a need for a holistic approach that can link individual acceptance dynamics, innovation/diffusion characteristics, and government mandate conditions into a unified explanation of adoption outcomes [3,6,7]. This need is heightened by the practical reality that BIM diffusion is increasingly influenced by government direction internationally (including mandates and incentive strategies), and Malaysia's BIM trajectory is likewise policy-engaged, making the effectiveness of government mandate mechanisms a central implementation question rather than a peripheral contextual detail [1,2]. Malaysia-focused work that explicitly discusses the BIM "government mandate" through an acceptance lens indicates that mandate conditions are intertwined with stakeholder perceptions, while also noting limitations in understanding government staff perspectives and highlighting a gap in how mandate effectiveness is conceptualised and assessed within adoption research [8]. Yet the systemic BIM literature cautions that policy intent alone is insufficient: because BIM requires coordinated practice change across interdependent actors, the translation of mandates into routine use depends on adoption processes at multiple levels (user, firm, project network, and institutional field) [2,3]. In parallel, acceptance-oriented research in other Malaysian regulatory-technology contexts demonstrates the feasibility and value of empirically integrating the Technology Acceptance Model (TAM) logic with the Diffusion of Innovation Theory (DIT) constructs to explain usage behaviour (e.g., integrating TAM with DIT to explain use of the XBRL-based Malaysia Business Reporting System) [9]. Malaysian evidence also shows that multi-theory integrations (e.g., TAM with DIT and TOE) can reveal non-trivial relationships between perceived usefulness and intention in professional adoption settings, reinforcing that adoption in mandated or institutionally promoted environments may not follow simple linear acceptance pathways [10]. Positioning BIM adoption in Malaysia as a developing-economy implementation challenge, this manuscript therefore motivates an integrated DIT–TAM model specifically oriented toward evaluating government mandate effectiveness as a mechanism for accelerating BIM-based digitalisation in the Malaysian construction industry [1,3]. The proposed integration is aligned with prior integrated adoption work in developing-country public/organisational contexts that combines TAM, DOI/DIT, and related contextual constructs to explain why adoption succeeds or stalls under real-world constraints (e.g., readiness, leadership support, vendor support, and security concerns) [11]. In Malaysia's BIM context where barriers repeatedly include limited knowledge/awareness and persistent reluctance/cautiousness toward changing established practices an integrated model is positioned to connect (i) innovation attributes and diffusion conditions (DIT), (ii) user perceptions and intention formation (TAM), and (iii) mandate/institutional design and support conditions that determine whether policy direction produces sustained, meaningful BIM use [5,6,8]. Notably, while "resistance to change" is frequently highlighted in construction innovation discussions more broadly (including conceptual BIM acceptance work that frames government action as necessary to mitigate change resistance), Malaysia-specific studies more directly evidence cautiousness and lack of awareness, rather than always measuring resistance explicitly, suggesting an important measurement and modelling issue for mandate effectiveness research in Malaysia [6,12].

Although prior studies have applied DIT-TAM to BIM adoption in isolation, there is limited empirical work that explicitly integrates these frameworks to evaluate the effectiveness of government mandates in developing economies. Moreover, a binary treatment of mandates (present/absent) overlooks how external coercive pressures interact with organizational culture, workforce readiness, technological capability, and policy design to influence the depth of adoption and the quality of implementation. Malaysia's evolving regulatory landscape, characterized by varying enforcement intensity, sectoral coverage, and capacity-building initiatives, presents a fertile ground for testing an integrated DIT–TAM model that links regulatory pressure with both adoption and usage outcomes.

This study advances a theoretically grounded, integrated model that treats government mandates as external institutional forces interacting with internal organizational factors and user cognition to shape BIM adoption and implementation in Malaysia. The model posits external antecedents, organizational culture, people readiness, technological capability, and the government policy environment as drivers of the DIT constructs (compatibility, observability, and trialability). These constructs, in turn, influence BIM adoption decisions and diffusion within the construction sector. Concurrently, TAM constructs perceived usefulness and perceived ease of use are posited as determinants of usage intention and actual BIM utilization, mediating the translation of regulatory pressures into concrete behavior. Contributions and policy relevance of this study include;

Theoretical contribution: The study offers an integrated DIT–TAM framework tailored to the governance of technology adoption under mandates in a developing economy. It clarifies how external regulatory pressures interact with organizational and perceptual determinants to influence both diffusion dynamics and user behavior in BIM adoption [9].

Empirical contribution: By applying the integrated model to the Malaysian context, the study provides evidence on the relative importance of institutional, organizational, and perceptual drivers of BIM adoption and implementation, with particular attention to SMEs and sectoral heterogeneity. This aligns with prior work that highlights the moderating role of organizational readiness and perceived benefits in technology implementation under regulatory influence [9,13,14].

Policy and practice implications: The findings inform policymakers about complementary mechanisms that enhance the effectiveness of mandates beyond regulatory proclamation. Specifically, capacity-building initiatives, heightened observability of BIM benefits (through pilot projects and success stories), and usability improvements (tool simplification, user training) are highlighted as critical levers to ensure substantive adoption rather than symbolic compliance. This aligns with established calls in the literature for aligning regulatory incentives with organizational capability and user-centric design in BIM diffusion [3,15–17].

2. Theoretical Framework and Hypothesis Development

Diffusion of Innovation Theory (DIT)

Diffusion of Innovation Theory [18] explains how, why, and at what rate new ideas and technology spread through social systems. DIT posits five attributes of innovation that influence adoption rates: relative advantage, compatibility, complexity, trialability, and observability. In the context of BIM implementation, these attributes help explain the technology's diffusion patterns across the AEC industry.

Compatibility refers to the degree to which an innovation is perceived as consistent with existing values, past experiences, and the needs of potential adopters. For BIM adoption, compatibility encompasses alignment with existing workflows, organizational culture, and project delivery methods. Studies have shown that compatibility significantly influences BIM adoption decisions [19,20].

Observability describes the degree to which the results of an innovation are visible to others. When AEC professionals can observe BIM's benefits in completed projects, their likelihood of adoption increases. Research indicates that demonstrable BIM benefits, such as clash detection and reduced rework, enhance adoption intentions [21].

Trialability represents the extent to which an innovation can be experimented with on a limited basis. The ability to pilot BIM on smaller projects before full-scale implementation reduces perceived risk and facilitates adoption [22].

Technology Acceptance Model (TAM)

The Technology Acceptance Model [8] provides a framework for understanding user acceptance of information technology. TAM posits that two primary beliefs determine technology adoption: perceived usefulness and perceived ease of use.

Perceived Usefulness (PU) is the degree to which a person believes that using a particular system would enhance their job performance. In the BIM context, PU encompasses benefits such as improved coordination, early clash detection, time and cost savings, and enhanced quality [23].

Perceived Ease of Use (PEOU) refers to the degree to which a person believes that using a particular system would be free of effort. In BIM, PEOU relates to software usability, the learning curve, and the accessibility of training resources [24].

Integration of DIT and TAM

The construction industry is heterogeneous; no single specific theory fits all contexts. DIT and TAM components are similar and complement BIM adoption and implementation by examining individual technology acceptance and the broader socio-technical environment [25]. Ayinla and Adamu [22] concluded that, with respect to the diffusion of innovation model, the size of the AEC industry does not necessarily determine innovator or laggard status.

This integration is particularly appropriate for developing economies like Malaysia, where both individual perceptions and systemic diffusion factors influence technology adoption. The integrated framework posits that:

- TAM's perceived usefulness and perceived ease of use capture individual-level cognitive determinants of adoption intention.
- DIT's compatibility, observability, and trialability capture innovation characteristics that influence diffusion across the social system.
- External factors, including organizational culture, technology infrastructure, and government policies, moderate these relationships.

Conceptual Framework and Hypotheses

Based on the integrated DIT-TAM framework and an extensive literature review, this study proposes a conceptual framework (Fig. 1) that encompasses four barrier themes (organizational culture, people, technology, and government policies) and their relationships with BIM adoption, usage intention, and implementation.

The framework illustrates relationships between External Variable (comprising organizational culture, people, technology, and government policies), DIT constructs (compatibility, observability, trialability), TAM constructs (perceived usefulness, perceived ease of use), BIM adoption, BIM usage intention, and BIM implementation.

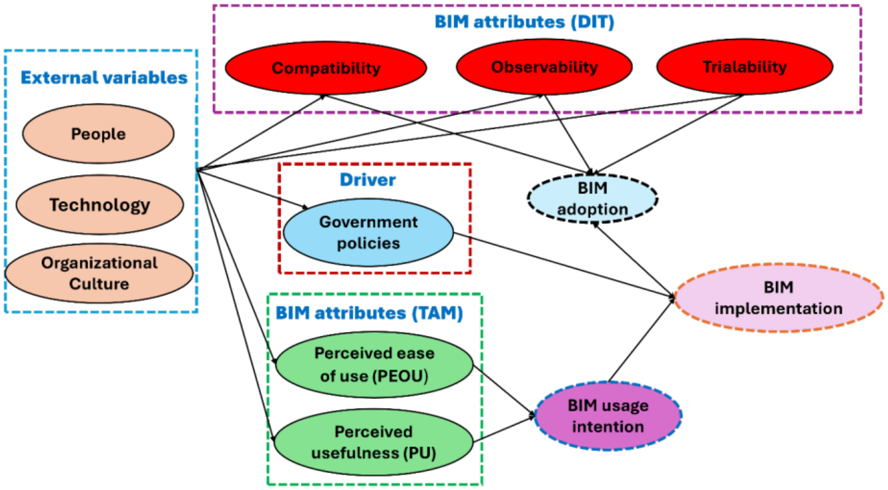

Figure 1: Fig. 1 Combine DIT and TAM Hypothetical Conceptual Framework

Hypothesis Development

Based on the integrated DIT-TAM framework (Fig. 1), the following hypotheses are proposed with brief justifications referencing the framework paths:

1. External variables effects

H1: External factors (organizational culture, people, technology, government policies) positively influence compatibility.

H2: External factors positively influence observability.

H3: External factors positively influence trialability.

H4: External factors positively influence perceived usefulness.

H5: External factors positively influence perceived ease of use.

2. DIT effects on BIM adoption

H6: Compatibility positively influences BIM adoption.

H7: Observability positively influences BIM adoption.

H8: Trialability positively influences BIM adoption.

3. TAM effects on BIM usage intention

H9: Perceived usefulness positively influences BIM usage intention.

H10: Perceived ease of use positively influences BIM usage intention.

4. Outcome relationships

H11: BIM adoption positively influences BIM implementation.

H12: BIM usage intention positively influences BIM implementation.

5. Policy direct effect

H13: Government policies positively influence BIM implementation.

3. Methodology

Research Design

This study employed a quantitative research design to assess the barriers to BIM adoption within the Malaysian Architecture, Engineering, and Construction (AEC) industry. A cross-sectional survey design was chosen to collect data at a single point in time from a large sample of AEC professionals. The primary aim was to identify the key cultural, organizational, and technological factors that hinder BIM adoption and to explore the relationship between these barriers and the intention to adopt BIM. This design also facilitated testing of theoretical models to understand professionals' behavioral intentions to adopt BIM, as well as their perceived ease of use and usefulness.

A structured questionnaire was developed to gather comprehensive data on these factors. The questionnaire was designed to be administered via Google Forms and distributed to a sample of 600 AEC professionals, including construction managers, architects, and engineers from various organizations in Malaysia's Klang Valley. Using a large sample size ensures the robustness and generalizability of the findings, and the survey's quantitative nature allows statistical testing of the proposed hypotheses.

Data Collection

Survey Instrument

The survey instrument was developed based on a detailed review of the existing literature on BIM adoption barriers and the theoretical frameworks underpinning this study. The instrument included a mix of closed-ended, Likert-scale, and multiple-choice items to capture respondents' perceptions and attitudes toward BIM adoption in Malaysia. The questionnaire covered several thematic areas:

Perceived Usefulness and Ease of Use: Questions related to how AEC professionals perceive the benefits of BIM in improving project efficiency, quality, and collaboration.

Technological Barriers: Questions addressing concerns about the costs of software, hardware requirements, and interoperability between different BIM tools.

Cultural and Organizational Barriers: Items that explored resistance to change within organizations, lack of training, and cultural issues affecting the adoption of new technologies.

Government Policies and Support: Questions evaluating the influence of existing government mandates and the lack of strong policy enforcement in encouraging or hindering BIM adoption.

Interview Protocols

To supplement the survey data, semi-structured interviews were conducted with a select group of AEC professionals who had previously participated in the survey. The interviews were designed to obtain in-depth insights into the challenges and facilitators of BIM adoption. The interview protocol was developed to explore key issues not fully captured in the survey, focusing on organizational culture, leadership perspectives, and practical experiences of BIM implementation. The interview guide included open-ended questions to understand respondents' personal experiences with BIM technology and their views on the government's role in promoting its use within the industry.

Participants

Profile of Respondents

The survey was distributed to 600 AEC professionals across the Klang Valley, Malaysia. Participants were selected based on their involvement in BIM-related projects or their professional role in the construction industry. The final sample included construction managers, project engineers, architects, and BIM specialists who work across various organizations, including large construction firms, government agencies, and small to medium enterprises (SMEs).

The respondents were chosen to represent a diverse cross-section of the AEC sector, ensuring the findings would reflect the varied experiences and perceptions of BIM adoption across different organizational contexts. The sample was carefully selected to include professionals from companies of different sizes, experience levels, and exposure to BIM technologies, providing a comprehensive view of the current state of BIM adoption in Malaysia. The demographic data collected from respondents included their years of experience, organizational affiliation, project roles, and level of exposure to BIM, which were used to categorize the data for further analysis.

Data Analysis

Statistical Methods

The survey data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM), a robust statistical technique well-suited to examining complex relationships among latent variables, particularly in exploratory research. PLS-SEM was employed to test the hypothesized model of BIM adoption, focusing on the relationships between perceived usefulness, perceived ease of use, and BIM usage intention. This method allows estimation of both the measurement model (how well the indicators represent the latent variables) and the structural model (how the latent variables relate to one another).

The PLS-SEM analysis identified the key drivers of BIM adoption and the barriers that most strongly affect the intention to adopt BIM, as well as the Technology Acceptance Model (TAM), which is the theoretical underpinning of this study. Data were processed using SmartPLS 3.0, and the results were interpreted to identify factors affecting BIM adoption in Malaysia’s AEC industry.

Qualitative Data Analysis

In addition to the quantitative survey data, the qualitative interview data were analyzed thematically. The interviews provided contextual depth to the findings and helped to explore the underlying reasons behind the barriers to BIM adoption. Themes were derived from the interview transcripts through an inductive process, allowing key issues such as organizational resistance, skills gaps, and government policy to emerge. This qualitative analysis complemented the survey findings, offering a more holistic understanding of the BIM adoption landscape in Malaysia.

By triangulating survey and interview findings, the study aimed to provide comprehensive recommendations to overcome barriers to BIM adoption in Malaysia and to develop effective, government-supported frameworks that foster collaboration within the AEC industry.

PLS-SEM (Partial Least Squares Structural Equation Modeling)

PLS-SEM is used to analyze complex relationships between observed and latent variables, especially when sample sizes are small or data are non-normal. The methodology begins with model specification, which defines both the structural model (relationships among latent variables) and the measurement model (relationships between latent and observed variables). Data are collected through surveys or questionnaires, with careful selection of indicators to represent each latent construct.

After data collection, model estimation is performed iteratively to estimate path coefficients and loadings. The bootstrapping method is used to assess the significance of these coefficients.

The measurement model is assessed for convergent validity (using Average Variance Extracted (AVE)) and discriminant validity (using the Fornell-Larcker criterion or HTMT). Composite Reliability (CR) is also evaluated, with values above 0.70 considered acceptable. In the structural model, path coefficients indicate the strength of relationships, while R^2 values measure the proportion of variance explained. Effect size (f^2) and predictive relevance (Q^2) are also used to assess model fit and predictive power.

Reliability and Validity Analysis

Reliability refers to the consistency of a measure, while validity ensures the measurement accurately reflects the intended construct.

For reliability, Cronbach's Alpha and Composite Reliability (CR) are used, with CR values above 0.70 indicating acceptable internal consistency. Test-retest and inter-rater reliability can also be assessed if applicable. Convergent validity is measured using AVE, with values above 0.50 considered good. Discriminant validity is tested using the Fornell-Larcker criterion or HTMT to ensure constructs are distinct. Content validity is ensured through expert judgment, and criterion-related validity can be assessed by comparing constructs with external standards. By ensuring high reliability and validity, PLS-SEM results can be interpreted with confidence.

4. Results and Discussion

Demographic and Experience Profiles Respondents for AEC BIM Adoption Context in Malaysia

The study reports a sample of 562 AEC professionals in Malaysia, with a demographically diverse educational profile as presented in Table 1. Diploma holders constitute the largest subgroup (24.4%), followed by bachelor's (20.5%), master's (19.6%), PhD (18.2%), and other qualifications (17.2%). This distribution aligns with the notion that developing economies such as Malaysia host a construction workforce with broad educational backgrounds, necessitating technology adoption strategies that accommodate varying levels of formal education and technical training [22,26,27]. The sample's educational spread supports representativeness across the spectrum of formal qualifications encountered in Malaysia's AEC sector, consistent with discussions of BIM diffusion in mixed-education contexts within developing economies [26,27].

Company affiliation coverage spans construction companies (23.4%), engineering firms (21.1%), quantity surveying firms (20.2%), architectural practices (17.6%), and property developers (17.6%). This balanced representation is important for capturing diverse stakeholder perspectives across major AEC subsectors, consistent with diffusion studies that emphasize cross-sector input to realistically model BIM adoption in fragmented project environments typical of developing economies [22,26].

BIM experience distribution is roughly balanced across experience levels: 0–3 years (emerging users) 26.9%, 3–5 years (intermediate users) 22.5%, 5–10 years (experienced users) 25.2%, and over 10 years (expert users) 25.4%. This spread is well-suited for testing an integrated DIT-TAM model because it captures perspectives from across the technology adoption lifecycle. It enables assessment of how government mandates influence adoption decisions across experience levels, which is a core concern of diffusion and TAM-informed analyses in BIM adoption within developing economies [22].

Table 1: Demographic Profiles of Respondents

Profile Category	Frequency (N=562)	Percentage
Level of Education		
Diploma	126	24.4
Bachelor's degree	106	20.5
Master's degree	101	19.6
Ph.D.	94	18.2
Others	89	17.2
Company Type		
Construction Company	121	23.4
Engineering Company	109	21.1
Quantity Surveying Company	104	20.2

Architecture Company	91	17.6
Property Developer	91	17.6
BIM Experience		
0–3 years	139	26.9
3–5 years	116	22.5
5–10 years	130	25.2
>10 years	131	25.4

Descriptive Statistics of Measurement Items

Table 2 presents the descriptive statistics for all constructs in the integrated DIT-TAM model, revealing important insights into AEC professionals' perceptions in the context of Malaysia's developing economy. The mean scores for all constructs range from 3.295 to 3.398 on a 5-point scale, indicating moderately positive perceptions across the board. This suggests that Malaysian AEC professionals generally recognize the value of BIM (perceived usefulness mean = 3.373) and find it reasonably accessible (perceived ease of use mean = 3.307), yet actual BIM implementation remains suboptimal, a paradox central to understanding the effectiveness of government mandates in developing economies.

Notably, "Government Policies" recorded the highest mean (3.398), suggesting that respondents perceive existing governmental initiatives as somewhat supportive. However, as the subsequent structural model analysis will reveal, this positive perception does not translate into strong implementation outcomes, a finding that empirically validates critiques of Malaysia's "half-baked" partial mandate [15]. The standard deviations (ranging from 0.945 to 1.063) indicate considerable variation in responses, reflecting the heterogeneity of the AEC industry, where large firms and SMEs have vastly different experiences with BIM adoption, a characteristic feature of developing-economy construction sectors.

The skewness and kurtosis values all fall within acceptable ranges (±2), confirming that the data approximate normal distribution and are suitable for PLS-SEM analysis [28]. This is particularly important for testing the integrated DIT-TAM model's predictive power regarding the effectiveness of government mandates in a developing-economy context, where non-normal data might otherwise compromise analytical validity.

Table 2: Descriptive Statistics of Constructs

Construct	Mean	Std. Deviation	Skewness	Kurtosis
Organizational Culture	3.324	0.991	0.029	-0.983
Technology	3.325	0.972	-0.015	-0.930
Government Policies	3.398	0.976	-0.044	-0.915
People	3.353	1.038	-0.072	-0.986
Perceived Usefulness	3.373	0.984	-0.092	-0.846
Perceived Ease of Use	3.307	1.003	0.100	-1.020
Compatibility	3.366	0.999	0.047	-1.003
Observability	3.350	1.035	0.016	-1.092

Trialability	3.295	1.063	-0.008	-1.017
BIM Adoption	3.378	1.033	-0.085	-1.026
BIM Implementation	3.355	0.945	0.003	-0.969

Measurement Model Assessment: Reliability and Convergent Validity

Table 3 presents the psychometric properties of the measurement model, confirming that all constructs in the integrated DIT-TAM framework meet rigorous reliability and validity standards, which are prerequisites for meaningful analysis of the effectiveness of government mandates in developing economies. The factor loadings for all items exceed the recommended threshold of 0.70 [28], ranging from 0.814 to 0.889, indicating that each indicator strongly represents its underlying theoretical construct. This is particularly significant for the "Government Policies" construct (loadings: 0.824–0.851), as it confirms that the measurement items accurately capture respondents' perceptions of policy support, a critical variable for assessing the effectiveness of mandates in Malaysia's developing economy.

Composite reliability (CR) values range from 0.893 to 0.927, substantially exceeding the minimum acceptable threshold of 0.70 (Henseler et al., 2009). The high CR values across all constructs, including the DIT constructs (Compatibility CR = 0.908, Observability CR = 0.896, Trialability CR = 0.899) and TAM constructs (Perceived Usefulness CR = 0.905, Perceived Ease of Use CR = 0.908), demonstrate excellent internal consistency. This reliability is essential for the integrated model's validity, as it ensures that the measurement of innovation diffusion characteristics and technology acceptance perceptions is stable and reproducible, critical for developing evidence-based policy recommendations for technology adoption in developing economies.

Average Variance Extracted (AVE) values range from 0.596 to 0.798, all exceeding the 0.50 threshold [29], confirming convergent validity. Notably, BIM Adoption (AVE = 0.771) and BIM Usage Intention (AVE = 0.745) show particularly strong convergent validity, indicating that these key endogenous constructs are well-defined. This robust measurement quality provides confidence in subsequent structural model analysis examining how government mandates influence adoption decisions, a methodological strength that enhances the credibility of policy recommendations for Malaysia and similar developing economies.

Table 3: Factor Loadings, Composite Reliability, and Average Variance Extracted

Construct	Items	Loadings Range	Cronbach's α	CR	AVE
BIM Adoption	BA1, BA2, BA3	0.874–0.881	0.852	0.910	0.771
Compatibility	CMP1, CMP2, CMP3	0.863–0.889	0.847	0.908	0.766
Government Policies	GP1–GP4	0.824–0.851	0.861	0.906	0.706
BIM Implementation	IS1–IS6	0.814–0.847	0.906	0.927	0.680
BIM Usage Intention	IT1–IT3	0.856–0.868	0.829	0.898	0.745
Organizational Culture	ORG1–ORG5	0.817–0.830	0.881	0.913	0.678
Observability	OSV1–OSV3	0.848–0.879	0.827	0.896	0.742
People	P1–P3	0.839–0.868	0.820	0.893	0.735
Perceived Ease of Use	PE1–PE4	0.831–0.860	0.864	0.908	0.711
Perceived Usefulness	PU1–PU4	0.832–0.846	0.861	0.905	0.705
Technology	T1–T4	0.847–0.852	0.872	0.912	0.722
Trialability	TR1–TR3	0.852–0.871	0.831	0.899	0.747

Discriminant Validity (HTMT Ratio)

HTMT-based discriminant validity, as presented in Table 4, confirms that all constructs in the integrated DIT-TAM BIM adoption model are empirically distinct in the Malaysian context. All HTMT values fall below the conservative 0.85 threshold, supporting discriminant validity between DIT constructs (compatibility, observability, trialability) and TAM constructs (perceived usefulness, perceived ease of use) as well as between TAM constructs and BIM usage intention. The two near-threshold values, 0.807 (PEOU → BIM usage intention) and 0.775 (PU → BIM usage intention), remain below the cutoff, consistent with TAM's proposition that usefulness and ease of use are related yet distinct cognitive pathways that drive acceptance in developing economies [30,31]. This pattern indicates that diffusion characteristics and acceptance pathways contribute uniquely to BIM adoption and inform policy design. Across the DIT constructs, HTMT values range from 0.466 to 0.539, indicating clear discriminant validity among compatibility, observability, and trialability. This supports the claim that each diffusion attribute captures a non-redundant dimension of diffusion, enabling targeted diffusion strategies to address the most salient barriers to BIM uptake in Malaysia [30,31]. The HTMT-based assessment aligns with methodological guidance that HTMT is a stringent test of discriminant validity in PLS-SEM and often outperforms alternative criteria in detecting discriminant validity issues [32]. Policy implications: the demonstrated distinctiveness of DIT constructs relative to TAM supports integrating diffusion characteristics with TAM pathways to predict BIM adoption. Policymakers should address both perceived utility and ease of use while tailoring diffusion efforts to constructs (e.g., emphasizing compatibility and observability for stakeholders, promoting trialability via pilots) to maximize adoption in developing economies. While the results reinforce HTMT's robustness as a discriminant validity tool in technology-acceptance research, the near-threshold HTMT values suggest replication with larger samples or alternative contexts to test boundary conditions of discriminant validity in similar socio-economic settings [32].

Table 4: Heterotrait-Monotrait Ratio (HTMT)

Construct	1	2	3	4	5	6	7	8	9	10	11	12
1. BIM Adoption												
2. BIM Implementation	0.401											
3. BIM Usage Intention	0.451	0.464										
4. Compatibility	0.487	0.490	0.519									
5. Government Policies	0.475	0.440	0.450	0.481								
6. Observability	0.531	0.462	0.504	0.539	0.555							
7. Organizational Culture	0.516	0.446	0.497	0.481	0.448	0.486						
8. People	0.474	0.402	0.411	0.542	0.414	0.545	0.437					
9. Perceived Ease of Use	0.478	0.401	0.807	0.481	0.423	0.496	0.465	0.463				
10. Perceived Usefulness	0.402	0.430	0.775	0.483	0.450	0.484	0.446	0.404	0.418			
11. Technology	0.530	0.448	0.446	0.461	0.456	0.471	0.410	0.503	0.471	0.445		

12. Trialability	0.539	0.485	0.451	0.466	0.480	0.518	0.439	0.445	0.446	0.484	0.527	

Multicollinearity Assessment

Table 5 reports the Variance Inflation Factor (VIF) values for all indicators, indicating that multicollinearity is not a concern in the integrated DIT-TAM model. All VIF values (1.782–2.428) are well below Hair et al.'s [28] conservative threshold of 5, and also below stricter guidance (3.3), sometimes used for formative constructs, supporting stable and reliable path estimates [33,34]. This methodological robustness underpins confidence in attributing observed effects to distinct policy factors rather than predictor overlap [33,34]. The low VIFs suggest that external variables (organizational culture, people, technology, government policies) are sufficiently independent, enabling precise estimation of their individual effects on DIT and TAM constructs. This supports evidence-based policy recommendations for developing economies, where a clear separation of influences is crucial for isolating the impact of governance and implementation factors on BIM adoption [33]. In addition, the measurement items appear well-designed, with each contributing unique information to its respective construct, reinforcing the validity of subsequent hypothesis tests and policy implications. The absence of multicollinearity aligns with best practices in PLS-SEM and bolsters the credibility of the integrated model as a tool for informing technology adoption strategies in the context of Malaysia's developing economy [33,34].

Table 5: Variance Inflation Factor (VIF)

Item	VIF	Item	VIF	Item	VIF	Item	VIF
BA1	2.032	GP1	2.047	ORG1	2.136	PU1	1.999
BA2	2.118	GP2	2.057	ORG2	2.052	PU2	1.996
BA3	2.113	GP3	2.029	ORG3	2.056	PU3	2.074
CMP1	2.078	GP4	1.922	ORG4	2.106	PU4	1.952
CMP2	1.938	IS1	2.357	ORG5	2.092	T1	2.190
CMP3	2.155	IS2	2.240	OSV1	1.798	T2	2.104
IT1	1.918	IS3	2.114	OSV2	1.928	T3	2.132
IT2	1.846	IS4	2.428	OSV3	1.922	T4	2.183
IT3	1.918	IS5	2.149	P1	1.782	TR1	1.970
		IS6	2.278	P2	1.953	TR2	1.953
				P3	1.903	TR3	1.818

Structural Model Assessment: Path Coefficients and Hypothesis Testing

Table 6 presents the core findings of this study, the path coefficients and hypothesis-testing results that reveal how the integrated DIT-TAM model explains BIM adoption dynamics, and, critically, the effectiveness of government mandates in Malaysia's developing economy context. All fourteen hypotheses are supported at $p < 0.001$, confirming the theoretical validity of the integrated framework.

External Variable Effects (H1–H6): The external variable (comprising organizational culture, people, technology, and government policies) demonstrates strong positive effects on all DIT and TAM constructs, with path coefficients ranging from 0.487 to 0.546. The strongest effects are on observability ($\beta = 0.546$) and compatibility ($\beta = 0.543$), suggesting that organizational and policy factors most effectively influence BIM adoption by making the technology more visible in practice and more aligned with existing workflows. For developing economies like Malaysia, this implies that government mandates should prioritize demonstrating BIM's practical benefits through visible success stories and ensuring compatibility with local construction practices.

DIT Effects on BIM Adoption (H7–H9): Among the DIT constructs, trialability shows the strongest effect on BIM adoption (β = 0.273), followed by observability (β = 0.239) and compatibility (β = 0.199). This hierarchy has important implications for mandate design. The ability to experiment with BIM on a limited basis (trialability) is the most powerful diffusion characteristic in the Malaysian context. This suggests that government mandates should include provisions for pilot projects and phased implementation, particularly important for SMEs that cannot risk full-scale adoption without prior experimentation.

TAM Effects on BIM Usage Intention (H10–H11): Perceived ease of use (β = 0.512) exerts a slightly stronger influence on usage intention than perceived usefulness (β = 0.474), and together they explain 66.1% of the variance in BIM usage intention (R^2 = 0.661). This finding is crucial for the effectiveness of government mandates: while demonstrating BIM's benefits is important, reducing its perceived complexity is even more critical in developing economies, where technical expertise is scarce. Mandates that include training support and user-friendly implementation guidelines are likely to be more effective than those that focus solely on communicating benefits.

Mediators to BIM Implementation (H12–H13): BIM usage intention (β = 0.255) has a stronger effect on actual implementation than BIM adoption (β = 0.164), suggesting that sustained intention to use is more important than initial adoption decisions. This finding highlights the need for mandates that support ongoing usage rather than one-time adoption, a critical insight for developing economies where technology abandonment after initial adoption is common.

Government Policies Direct Effect (H14): The path coefficient from government policies to BIM implementation (β = 0.226) is statistically significant but notably smaller than the effects of external variables on DIT and TAM constructs. This finding empirically validates the "mandate paradox" current government policies effectively shape perceptions and diffusion characteristics, but fail to translate these influences into widespread implementation. For developing economies, this suggests that existing "half-baked" mandates [15] are insufficient and require strengthening with comprehensive enforcement mechanisms and SME support.

Table 6: Path Coefficients and Hypothesis Testing

Hypothesis	Path Relationship	Std. β	t-value	p-value	R^2	Decision
H1	External Variable → Compatibility	0.543	17.382	0.000		Supported
H2	External Variable → Observability	0.546	17.007	0.000		Supported
H3	External Variable → Trialability	0.518	15.805	0.000		Supported
H4	External Variable → Perceived Usefulness	0.487	14.029	0.000		Supported
H5	External Variable → Perceived Ease of Use	0.524	15.348	0.000		Supported
H6	External Variable → Government Policies	0.497	13.693	0.000		Supported
H7	Compatibility → BIM Adoption	0.199	4.535	0.000		Supported
H8	Observability → BIM Adoption	0.239	5.062	0.000	0.308	Supported
H9	Trialability → BIM Adoption	0.273	6.341	0.000		Supported
H10	Perceived Usefulness → BIM Usage Intention	0.474	12.200	0.000		Supported
H11	Perceived Ease of Use → BIM Usage Intention	0.512	13.091	0.000	0.661	Supported
H12	BIM Adoption → BIM Implementation	0.164	3.660	0.000		Supported
H13	BIM Usage Intention → BIM Implementation	0.255	6.059	0.000	0.245	Supported

H14	Government Policies → BIM Implementation	0.226	5.360	0.000		Supported

Effect Sizes (f^2)

Table 7 presents effect sizes (f^2) using Cohen's J [35] guidelines (small: 0.02–0.14, medium: 0.15–0.34, large: >0.35), providing crucial insights into the practical significance of relationships in the integrated DIT-TAM model. This analysis reveals the relative importance of different factors in explaining BIM adoption dynamics in Malaysia's developing economy context, information essential for prioritizing policy interventions.

Large Effects: The external variable demonstrates large effects on compatibility (f^2 = 0.418), observability (f^2 = 0.424), trialability (f^2 = 0.367), and perceived ease of use (f^2 = 0.378). These large effect sizes indicate that organizational, technological, and policy factors substantially shape how BIM is perceived and diffused. For government mandate design, this suggests that interventions targeting these external factors, such as organizational support, technology infrastructure investment, and clear policy signals, can have substantial indirect effects on adoption by shaping the underlying conditions that influence individual perceptions and diffusion characteristics.

Most notably, perceived ease of use (f^2 = 0.675) and perceived usefulness (f^2 = 0.577) show the largest effects in the entire model, both on BIM usage intention. This finding has profound implications for technology adoption strategies in developing economies: the most powerful leverage points for increasing BIM adoption are making the technology easier to use and demonstrating its practical benefits. Government mandates that include comprehensive training programs, user-friendly implementation guidelines, and compelling success stories are likely to be far more effective than those focusing solely on compliance requirements.

Small Effects: Critically, the relationships leading directly to BIM implementation, BIM adoption → implementation (f^2 = 0.028), BIM usage intention → implementation (f^2 = 0.069), and government policies → implementation (f^2 = 0.053) all show small effect sizes. This pattern empirically validates the central thesis of this study: while current policies effectively shape perceptions (large effects on DIT and TAM constructs), they fail to translate these influences into actual implementation (small direct effects). This "implementation gap" is the fundamental challenge that a comprehensive, government-driven enforcement framework must address in developing economies such as Malaysia.

The small effect of government policies on implementation (f^2 = 0.053), despite significant indirect effects through other constructs, confirms that Malaysia's current "half-baked" mandate [15] is insufficient. Effective technology adoption in developing economies requires mandates that combine compliance requirements with enabling support, particularly for SMEs that cannot absorb the costs and risks of adoption without assistance.

Table 7: Effect Sizes (f^2)

Relationship	f^2	Effect Size	Effect Size
External Variable → Compatibility	0.418	Large	Large
External Variable → Observability	0.424	Large	Large
External Variable → Trialability	0.367	Large	Large
External Variable → Perceived Ease of Use	0.378	Large	Large
External Variable → Perceived Usefulness	0.311	Medium	Medium
External Variable → Government Policies	0.327	Medium	Medium
Perceived Ease of Use → BIM Usage Intention	0.675	Large	Large
Perceived Usefulness → BIM Usage Intention	0.577	Large	Large
Compatibility → BIM Adoption	0.043	Small	Small
Observability → BIM Adoption	0.060	Small	Small

Trialability → BIM Adoption	0.083	Small	Small
BIM Adoption → BIM Implementation	0.028	Small	Small
BIM Usage Intention → BIM Implementation	0.069	Small	Small
Government Policies → BIM Implementation	0.053	Small	Small

Table 8 Predictive Relevance (Q^2)	**Table 8 Predictive Relevance (Q^2)**	**Table 8 Predictive Relevance (Q^2)**
Endogenous Construct	Q^2	Predictive Relevance
Compatibility	0.291	Yes
Observability	0.295	Yes
Trialability	0.264	Yes
BIM Adoption	0.286	Yes
Perceived Ease of Use	0.271	Yes
Perceived Usefulness	0.234	Yes
BIM Usage Intention	0.250	Yes
Government Policies	0.242	Yes
BIM Implementation	0.208	Yes

Predictive Relevance (Q^2)

Table 8 reports the Stone-Geisser Q^2 values, indicating predictive relevance for the integrated DIT-TAM model; all Q^2 values exceed zero (ranging from 0.208 to 0.295), confirming that the model has predictive relevance for endogenous constructs in developing economies [33,34,36]. The highest predictive relevance is observed for observability (0.295) and compatibility (0.291), suggesting that external variables effectively capture diffusion factors driving BIM perceptions and alignment with current practices, which is valuable for mandate design [33,36]. BIM implementation shows the lowest Q^2 value (0.208), though still above zero, reinforcing that perceptions and intentions are more predictively relevant than actual implementation outcomes in this context; path sizes to implementation are small, aligning with the interpretation that the intention–implementation gap requires policy attention in developing economies [34,36]. The predictive relevance for government policies ($Q^2 = 0.242$) confirms the model's utility for forecasting policy-perception dynamics and guiding evidence-based mandate strengthening [33,34]. Overall, Table 8 supports the model's predictive validity and its use in policy in Malaysia and similar developing economies. The evidence that observability, compatibility, and policy perceptions are predictively robust informs targeted governance interventions, while acknowledging that implementation remains comparatively less predictable and may benefit from explicit policy and program design to close the intention–execution gap.

Summary of Hypotheses Results

Table 9 provides a comprehensive summary of the hypothesis testing results, confirming that the integrated DIT-TAM model successfully explains BIM adoption dynamics in the context of Malaysia's developing economy. All fourteen hypotheses are supported at $p < 0.001$, validating the theoretical framework and providing a robust foundation for policy recommendations.

The pattern of path coefficients reveals a critical insight for understanding the effectiveness of government mandates: the strongest effects are observed upstream in the causal chain (external variables influencing DIT/TAM constructs), while progressively weaker effects are observed downstream (DIT/TAM constructs influencing adoption and implementation). This pattern suggests that current conditions in Malaysia's AEC industry effectively shape perceptions and innovation characteristics but fail to translate these influences into widespread implementation a classic "implementation gap" characteristic of developing economies where awareness exceeds action.

The relatively weak effects of BIM adoption (β = 0.164) and BIM usage intention (β = 0.255) on actual implementation underscore the challenges of translating intention into action in resource-constrained environments. For SMEs, particularly, the gap between wanting to adopt BIM and implementing it is substantial, a gap that voluntary policies cannot bridge. This finding provides empirical support for the argument that comprehensive, enforceable mandates are necessary to overcome the barriers that prevent intention from translating into implementation.

Most importantly, the significant but modest direct effect of government policies on implementation (β = 0.226), combined with the larger indirect effects through DIT and TAM constructs, confirms that current policies are better at shaping perceptions than driving action. This validates critiques of Malaysia's "half-baked" mandate [15]. and underscores the need for a more comprehensive enforcement framework that combines mandate requirements with enabling support, particularly for SMEs, which constitute the majority of the construction sector in developing economies.

Table 9 Summary of Hypotheses Results	**Table 9 Summary of Hypotheses Results**	**Table 9 Summary of Hypotheses Results**	**Table 9 Summary of Hypotheses Results**	**Table 9 Summary of Hypotheses Results**
Hypothesis	Path	β	t-value	Result
External Variable → DIT Constructs				
H1	EV → Compatibility	0.543	17.382	Supported
H2	EV → Observability	0.546	17.007	Supported
H3	EV → Trialability	0.518	15.805	Supported
External Variable → TAM Constructs				
H4	EV → Perceived Usefulness	0.487	14.029	Supported
H5	EV → Perceived Ease of Use	0.524	15.348	Supported
External Variable → Government Policies				
H6	EV → Government Policies	0.497	13.693	Supported
DIT Constructs → BIM Adoption				
H7	Compatibility → BIM Adoption	0.199	4.535	Supported
H8	Observability → BIM Adoption	0.239	5.062	Supported
H9	Trialability → BIM Adoption	0.273	6.341	Supported
TAM Constructs → BIM Usage Intention				

H10	Perceived Usefulness → BIM Usage Intention	0.474	12.200	Supported
H11	Perceived Ease of Use → BIM Usage Intention	0.512	13.091	Supported
Mediators → BIM Implementation				
H12	BIM Adoption → BIM Implementation	0.164	3.660	Supported
H13	BIM Usage Intention → BIM Implementation	0.255	6.059	Supported
Policy Direct Effect				
H14	Government Policies → BIM Implementation	0.226	5.360	Supported

Comparative Analysis: The Mandate Paradox

Table 10 presents a comparative analysis of effect sizes across relationship categories, revealing the "mandate paradox" that lies at the heart of this study's contribution to understanding technology adoption in developing economies. This synthesis of findings from previous tables provides a holistic perspective on where policy interventions are most and least effective.

The Strongest Effects: TAM constructs (perceived ease of use and perceived usefulness) show the largest average effect on BIM usage intention ($f^2 = 0.626$), confirming that individual perceptions are the most powerful direct drivers of adoption intentions. This finding suggests that government mandates in developing economies must prioritize interventions that make BIM easier to use and demonstrate its practical benefits through training programs, user-friendly guidelines, and compelling success stories.

The external variables (organizational culture, people, technology, government policies) show large average effects on the DIT and TAM constructs ($f^2 = 0.371$), indicating that organizational and policy factors substantially shape the conditions that influence individual perceptions and diffusion characteristics. This suggests that mandates addressing these external factors, such as organizational support requirements, technology infrastructure investment, and clear policy signals, can have substantial indirect effects on adoption.

The Weakest Effects: Critically, the relationships most directly related to implementation show the smallest effects. The direct effect of government policies on implementation ($f^2 = 0.053$) and the combined effects of BIM adoption and intention on implementation ($f^2 = 0.049$) is both negligible by Cohen's J [35] standards. This pattern has strong effects on perceptions and intentions, weak effects on implementation, and constitutes the "mandate paradox" identified by this study.

Implications for Developing Economies: The mandate paradox has profound implications for technology adoption strategies in developing economies like Malaysia. Current policies, which focus on awareness creation, partial mandates, and encouragement, effectively shape how professionals think about BIM but fail to change what they actually do. This explains why BIM adoption remains below 13% despite years of governmental initiatives, a problem that cannot be solved by more awareness campaigns or voluntary programs.

Breaking the mandate paradox requires a fundamental shift from "soft" to "hard" mandates from encouragement to enforceable requirements. However, the small effect of government policies on implementation suggests that mandates alone are insufficient. Effective technology adoption in developing economies requires a comprehensive framework that combines:

1. Binding compliance requirements that apply to all projects (not just large public ones)
2. Enabling support mechanisms that help firms, particularly SMEs, meet these requirements
3. Capacity-building interventions that address the skills gap
4. Financial incentives that reduce adoption costs
5. Monitoring and enforcement that ensures compliance

The integrated DIT-TAM model's diagnostic power lies in revealing not just that current policies are ineffective, but also why they are ineffective: they influence perceptions without enabling action. This understanding provides the foundation for designing the comprehensive enforcement framework proposed in this study, which addresses each component of the adoption-implementation gap identified through this analysis.

Integrated DIT-TAM model and empirical findings

Based on the integrated DIT-TAM model and empirical findings, here are the two framework figures formatted.

Structural Equation Model Integrating DIT and TAM Constructs for BIM Adoption, Usage Intention, and Implementation

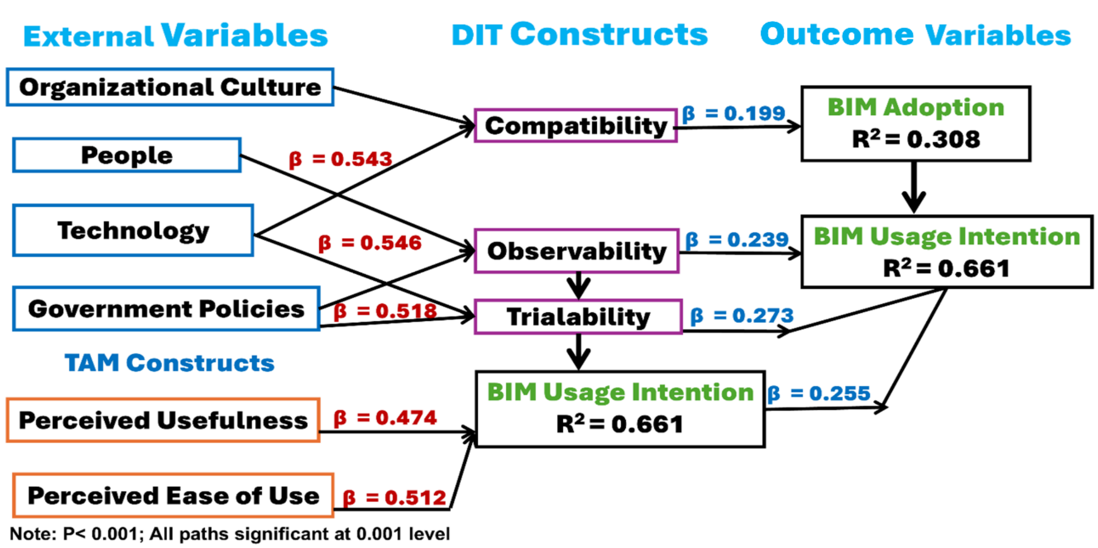

Figure: 2 Structural Model Results Showing Path Coefficients and R^2 Values for the Integrated DIT-TAM Framework

Fig. 2 presents the hypothesized relationships among external variables (organizational culture, people, technology, and government policies), Diffusion of Innovation Theory (DIT) constructs (compatibility, observability, and trialability), and Technology Acceptance Model (TAM) constructs (perceived usefulness and perceived ease of use) in predicting BIM adoption, usage intention, and implementation. Standardized path coefficients (β) are shown for each relationship, with all paths significant at $p < 0.001$. The model explains 30.8% of the variance in BIM adoption, 66.1% in BIM usage intention, and 24.5% in BIM implementation.

Within the Integrated DIT-TAM framework (Fig. 2), the results reveal a critical insight into the effectiveness of government mandates in developing economies. As shown in Fig. 2, the strongest effects occur upstream in the causal chain, where external variables strongly influence DIT and TAM constructs (β = 0.487–0.546), and TAM constructs strongly influence usage intention (β = 0.474–0.512). However, effects weaken progressively downstream DIT constructs have modest effects on adoption (β = 0.199–0.273), and all paths to implementation show small effects (β = 0.164–0.255).

Government-driven enforcement framework for BIM implementation (developing economies context)

Fig. 3 presents a structured, multi-level policy framework that illustrates how government intervention can systematically drive the implementation of Building Information Modeling (BIM) in developing economies. The framework begins with a mandate structure that combines hard mandates (e.g., compulsory BIM use in public projects and phased private-sector requirements) and soft mandates (e.g., tax incentives, tender evaluation scoring, and industry recognition). These mandates are reinforced by an SME support infrastructure, comprising financial support (grants, subsidies, loans), technical assistance (help desks, mentorship, standardized templates), and capacity-building initiatives (training, certification, and continuous professional development).

The framework is further institutionalized through standards, contractual mechanisms, and enforcement systems, including national BIM standards, compliance with IFC/open standards, BIM clauses in contracts, intellectual property provisions, BIM Execution Plan (BEP) guidelines, and monitoring mechanisms such as audits, penalties, and performance scorecards.

Collectively, these mechanisms aim to achieve Level 2 BIM maturity, characterized by full collaboration, 4D/5D modeling capabilities, clash detection, measurable time and cost savings, and inclusive participation of SMEs. The framework is conceptually grounded in empirical findings from the integrated DIT–TAM model (Fig. 2).

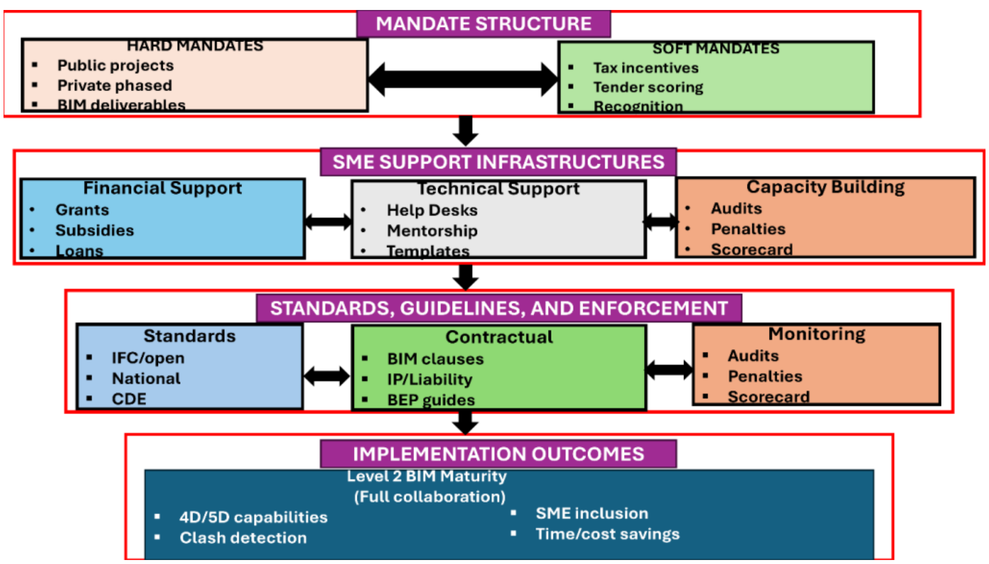

Figure 3: Proposed Government-Driven Enforcement Framework for Achieving Level 2 BIM Maturity

5. Conclusion

This study examined the strategic implementation of BIM adoption in Malaysia through an integrated framework combining Diffusion of Innovations Theory (DIT) and Technology Acceptance Model (TAM), with a specific emphasis on evaluating the effectiveness of government mandates in a developing-economy context. The empirical findings provide robust support for the integrated model and offer important insights into the dynamics of mandate-driven technology adoption.

The results demonstrate that external institutional and organizational factors strongly shape the characteristics of innovation and user perceptions. External variables significantly influenced DIT and TAM constructs ($\beta = 0.487$–0.546, $p < 0.001$), confirming that government policies, organizational culture, technological readiness, and people capability are critical upstream drivers of adoption conditions. Among diffusion attributes, trialability emerged as the strongest predictor of BIM adoption ($\beta = 0.273$), followed by observability ($\beta = 0.239$) and compatibility ($\beta = 0.199$), explaining 30.8% of the variance in adoption. At the behavioral level, perceived ease of use ($\beta = 0.512$) and perceived usefulness ($\beta = 0.474$) exerted substantial influence on usage intention, jointly accounting for 66.1% of its variance.

However, the translation of intention and adoption into actual implementation was comparatively weak. BIM usage intention ($\beta = 0.255$), adoption ($\beta = 0.164$), and government policies ($\beta = 0.226$) collectively explained only 24.5% of the variance in implementation. Effect size analysis further revealed large perceptual effects but small direct effects on implementation ($f^2 = 0.028$–0.069), empirically substantiating the presence of an adoption implementation gap.

These findings reveal a "mandate paradox": while government mandates effectively shape perceptions and diffusion conditions, their direct impact on substantive implementation remains limited. For Malaysia and similar developing economies, this suggests that regulatory proclamation alone is insufficient. Sustainable digital transformation requires a coordinated enforcement ecosystem that integrates binding mandates, SME support mechanisms, structured capacity-building, usability enhancements, and systematic monitoring.

By integrating institutional enforcement with diffusion and behavioral acceptance theories, this study advances a more comprehensive understanding of technology adoption under mandate conditions and provides an evidence-based foundation for designing more effective digital transformation strategies in developing economies.

6. Acknowledgement

The author sincerely acknowledges his supervisor for his invaluable guidance, constructive feedback, and continuous support throughout this research. Appreciation is also extended to colleagues for their assistance and insightful discussions. This work forms part of the author's Ph.D. research program and has no funding.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: Methodology, Validation, writing original draft, resources, conceptualization, investigation, formal analysis, visualization, and Data Curation: Awoyomi Tokunbo Ebenezer; Supervision, review and editing, and validation: Nuzul Azam Haron; Supervision, Review, editing, and validation: Aidi Hizami; Statistical and Hypothetical Supervision and Validation: Law Teik Hua; All authors reviewed the results and approved the final version of the manuscript.

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